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ABSTRACT

The relative rates of strength recovery subsequent to bouts of rhythmic or sustained isometric exercise were investigated. The 72 undergraduates who served as subjects were tested seven times within the framework of a repeated measures design. Each testing session involved two bouts of either rhythmic or sustained isometric exercise separated by a rest interval of 5, 10, 20, 40, 80, 160, or 320 seconds. Strength recovery was evaluated by comparing the level of strength expressed at the conclusion of the initial fatigue bouts, final strength, and the initial strength measure of the second exercise bouts. Analysis of variance and related statistics indicated that a) significant strength decrements of similar magnitude were produced by both types of activity; b) the group of subjects who initially performed rhythmic exercise consistently stronger than those performing sustained exercise; c) strength at the end of the first exercise bout was significantly lower than final recovery strength; and d) initial strength and final recovery strength failed to differ significantly. Although not in complete accord with previously published results, these results show that the patterns of strength recovery subsequent to rhythmic and sustained isometric exercise were similar. (Author)

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STRENGTH RECOVERY FOLLOWING RHYTHMIC OR SUSTAINED EXERCISE AS A FUNCTION OF TIME

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ABSTRACT

KEARNEY, Jay T., Ph.D. "Strength Recovery Following Rhythmic or Sustained Exercise as a Function of Time," Appalachian State University, Boone, North Carolina 28607.

The relative rates of strength recovery subsequent to bouts of rhythmic or sustained isometric exercise were investigated. The research involved implementation of methodological adaptations designed to provide a more realistic comparison of the relative rates of strength recovery. The results were consequently used to assist in resolution of the contradictions inherent in earlier studies.

The 72 undergraduates who voluntarily served as subjects were tested 7 times within the framework of a repeated measures design. Each testing session involved two bouts of either rhythmic or sustained isometric exercise separated by a rest interval of 5, 10, 20, 40, 80, 160, or 320 seconds. Strength recovery was evaluated by comparing the level of strength expressed at the conclusion of the initial fatigue bouts, final strength, and the initial strength measure of the second exercise bouts.

The analysis of variance and related statistics indicated that: (1) significant strength decrements of similar magnitude were produced by both types of activity; (2) the subjects who initially performed rhythmic exercise were consistently stronger than those performing sustained exercise; (3) strength at the end of the first exercise bout was significantly lower than final recovery strength; and (4) initial strength and final recovery strength failed to differ significantly. The exponential analyses revealed that both patterns of strength recovery were described adequately by two-component equations. The magnitude and rate constants of these curves were

also reasonably comparable. Although not in complete accord with previously published results it was concluded that on the basis of the present investigation the patterns of strength recovery subsequent to rhythmic and sustained isometric exercise were similar.

Introduction

Numerous researchers have sought to identify the extent, rate, and factors that significantly affect the nature of the recovery process. A brief review of a few selected studies indicates the sequential nature of work in the area as well as serving as a template for further investigative possibilities.

In 1962, Clarke[1] compared the rate and pattern of strength recovery subsequent to sustained and rhythmic exercise. The sustained bouts involved the maintenance of maximum grip-flexion exertion for two minutes while the rhythmic task required six minutes of alternate gripping and releasing at a cadence of 30 contractions per minute. A larger strength decrement was produced in response to the sustained activity. In order to facilitate a comparison of the parameters of recovery the author arbitrarily displaced the sustained recovery curve so that recovery under both conditions started at the same point. Subsequent to this adjustment recovery was shown to progress more rapidly after sustained exercise.

In a later study Clarke and Stull[3] hypothesized that the lack of similar strength decrements in response to Clarke's aforementioned fatigue tasks may have provided a greater potential for recovery following sustained activity. To eliminate this problem the authors conducted a study wherein the duration of the sustained activity bouts was adjusted so that recovery commenced from equivalent strength levels. Their results indicated that recovery was faster following rhythmic activity.

Further investigation lead Stull and Clarke[7] to evaluate strength recovery through the use of a repeated measures design with initially massed observations. The application of this design to the problem provided for an

improved description of strength recovery subsequent to both sustained and rhythmic activity. The authors reported that recovery was: (1) initially very rapid; (2) described adequately by a two-component exponential equation; and (3) faster following rhythmic activity.

In retrospect there appear to be at least two possible limitations in this experimental design. First, since Stull and Clarke[7] utilized a single maximum contraction as being indicative of recovery the subjects were aware that the test would be terminated after the effort, they may have exerted a greater percentage of their maximum physiological strength than was the case at any point during the initial fatigue bout. The second possible limitation, inherent only to the rhythmic condition was that during the fatigue bout a specified cadence had to be maintained but during recovery testing this factor was removed.

In an attempt to gain more information relative to the pattern of strength recovery subsequent to sustained and rhythmic isometric exercise the present investigation was undertaken. More specifically this research was undertaken to: (1) implement logical methodological adaptations designed to provide a more comprehensive and realistic comparison of the relative rates of strength recovery; (2) assist in the resolution of some of the contradictions inherent in earlier research which dealt with the relative rates of strength recovery.

Methodology

The research involved repeated testing of 72, male, undergraduate students between the ages of 18 and 28 years. Every subject was tested seven times, and each test involved two bouts of isometric grip flexion

exercise separated by a rest interval of 5, 10, 20, 40, 80, 160, or 320 seconds. All subjects experienced each recovery interval, and the order of administration of the intervals was determined by random selection. The subjects were assigned at random to four groups, and the groups were assigned randomly to each of the four possible permutations of rhythmic and sustained tasks. The sustained task involved a one-minute maximal bout on a movable modification of the Maryland dynograph.[2] The rhythmic task required a three-minute maximal effort on the same apparatus at a rate of 42 contractions per minute. The rhythmic strength curves were sampled at each 15-second interval and the sustained curves at each 5-second interval. The initial strength measure during the second exercise bouts was used to assess strength recovery.

Results

During the initial fatigue bouts, 36 subjects exercised rhythmically and 36 were tested while maintaining a sustained contraction. Descriptive statistics, indicative of the strength decrement and recovery occurring during activity and after the rest intervals, are presented in Table 1. The exact strength decrement remaining after each recovery interval may be seen in Table 2.

In order to determine if differences existed between the rhythmic and sustained strength scores an analysis of variance, summarized in Table 3, was computed. The significant $F = 9.08$ ($P < .05$) for the between groups analysis indicated that when averaged over all nine test levels (initial strength, final strength, and strength at the initiation of each of the seven second bouts), a greater amount of force was exerted during rhythmic

exercise. The consistent superiority of the rhythmic group over all test levels was suggested by the lack of significance of the groups-by-tests interaction term ($F = 1.63$). The within subjects comparison of the same analysis resulted in an F-ratio of 130.76 which revealed the existence of significant ($P < .05$) differences among the various test levels. In order to ascertain the location of the differences indicated by the significant F-ratio for tests, Tukey's w-procedure was used. Table 4, which summarizes the post-hoc comparisons, illustrates three important results: (1) initial strength was significantly greater than the strength exhibited at the termination of the initial fatigue bout; (2) strength at the end of the first exercise bout was significantly lower than final recovery strength; and (3) initial strength and final recovery strength failed to differ significantly.

A more complete understanding of recovery following both rhythmic and sustained exercise was provided by submitting the curves of strength recovery to exponential analysis. The pattern of strength recovery, subsequent to both types of activity, was described sufficiently by two-component exponential equation of the form:

$$Y_t = c - (a_1 e^{-k_1 t} + a_2 e^{-k_2 t}).$$

The parameters of the exponential curves are presented in Table 5. Figure 1 portrays the computed form of these curves as well as the observed data points.

Inspection of the curves and their parameters revealed that although the pattern subsequent to the sustained task was consistently lower than the rhythmic curve, they were quite comparable. The magnitude and rate constants of the initial component ($a_1 - k_1$) were very similar; however, the magnitude of the second component in the sustained recovery curve was less than that

following rhythmic exercise. This factor tended to produce a more asymptotic curve.

Discussion

The results of selected prior research have been compared with those of the present investigation. McArdle and Verel plotted the pattern of strength recovery for two subjects following grip-flexion exercise on a weight loaded ergograph. Although the original authors did not describe recovery in exponential terms, it appeared that the rate of strength recovery was comparable to that observed in the present study.

Lind[5] investigated the return of strength following sustained exercise and reported that his four subjects had regained 80 percent of the decrement within three minutes. This rate of strength return was also similar to that observed in the present study.

In 1962, Clarke[1] reported that 60 and 63 percent of the strength decrement had been recovered 60 seconds following the rhythmic and sustained tasks, respectively. These percentages were quite similar to the interpolated values of 60 and 68 percent obtained in the present investigation. However, Clarke's conclusion that recovery following sustained activity was faster than that subsequent to rhythmic activity was not supported herein.

The investigation by Clarke and Stull[3] which provided for equivalent final strength also produced results contradictory to the earlier conclusions. Subsequent to rhythmic exercise a significantly greater proportion (72 percent) of the strength decrement was regained during the first minute of recovery than following sustained activity (58 percent).

The results of the present study are not in complete accord with those of Clarke and Stull.[3] The form of the mathematical curves describing recovery

was the same in both studies; however, several of the exponential parameters were dissimilar. In the present study, the initial components following rhythmic and sustained activity were quite similar. In contrast to this, Clarke and Stull reported that following rhythmic activity the magnitude of the initial component was almost three times as large as following sustained exercise.

The rate constants at which the initial components were expressed were similar within both studies but slower in the present investigation. A possible explanation for this difference could be the increased frequency of sampling utilized during the early portion of recovery herein. The magnitude of the second components of the two studies were generally agreeable, but the rate constants were markedly slower in the present research. It is possible that the reason for this discrepancy was that Clarke and Stull[3] repeatedly measured strength during recovery and, therefore, the latter observations may have been depressed by the influence of prior testing.

Stull and Clarke[7] conducted an investigation wherein recovery was evaluated in a non-serial, initially massed fashion. The application of this design improved the description of recovery by: (1) massing the observations during the initial segment of the process when the greatest amount of recuperation was occurring; and (2) removing the possibilities of confounding due to serial testing.

In exponential terms the recovery curves of Stull and Clarke[7] were of the same form as those of the present research. The magnitude and rate constants of the components, however, were variable. The size of the a_1 following rhythmic exercise was almost twice as large as a_1 after sustained activity. The magnitudes of the second or main components within these studies

were reasonably comparable. The associated rate constants reported by Stull and Clarke were considerably faster than those of the present investigation. The net result of these differences was that the latter portions of the recovery curves were flatter in Stull and Clarke's study than in the present research. The explanation of this difference may be linked to the fact that Stull and Clarke used a single maximal effort to represent strength recovered, whereas the present study utilized the initial strength measures of the second fatigue bouts.

The percentage of strength decrement recovered at each time interval was noticeably lower in the present investigation than that reported by Stull and Clarke.[7] As previously mentioned these differences may be attributed to the subject's willingness to exert maximum force and the restricting nature of a required cadence. Consequently, it appears that by evaluating strength recovery through the use of the initial segment of a second fatigue curve a slower but perhaps more legitimate rate of recovery was observed. On the basis of their variant curve forms Stull and Clarke[7] concluded that the rate of strength recovery was faster after rhythmic activity. This finding is in contrast to the results of the present investigation which was unable to demonstrate any difference.

It should be noted that all of the patterns of the recovery of muscular strength that were discussed involved two exponential components. Although it was not the specific purpose of this investigation to identify the underlying physiological mechanisms responsible for strength recovery, it is of interest to note similarities between the pattern of strength recuperation and those of blood flow and oxygen debt pay-off. To assert on the basis of the results of this study that the rate of strength recovery was

controlled or limited by the time course of oxygen or blood flow debt pay-off would certainly be unfounded. The similar shape of these parameters responsible for replenishing the supply of high energy reserves, providing for the removal and/or oxidation of acid metabolites, and the restoration of thermal equilibrium, however, should not be ignored if one seeks to understand the basic physiological mechanisms responsible for the modulation of expressed strength.

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THE FOLLOWING TABLES AND FIGURE WERE PRESENTED AS SLIDES.

Table 1

Strength Recovery as a Function of Time[a]

Interval or Time of Recovery in Seconds	Rhythmic Exercise		Sustained Exercise	
	$\bar{x}$	s	$\bar{x}$	s
Initial Strength	52.72	9.75	48.38	9.70
Final Strength	30.94	7.60	25.38	5.99
5	34.94	8.46	30.39	6.43
10	37.17	8.19	31.68	7.57
20	37.72	8.34	35.28	8.13
40	42.93	9.74	36.82	8.20
80	46.98	10.21	41.51	8.70
160	47.47	10.05	42.77	8.19
320	52.84	10.10	44.57	9.60

[a]Statistics computed in kilograms.

Table 2

Strength Decrement Remaining Subsequent to Respective Rest Intervals[a]

Exercise	Time Recovery in Seconds							
	0	5	10	20	40	80	160	320
Rhythmic	21.78	17.97	15.55	15.00	9.79	5.79	5.25	-.12
Sustained	23.00	17.99	16.70	13.10	11.56	6.87	5.61	3.81

[a]Decrements expressed in kilograms.

Table 3

Analysis of Variance on Initial, Final, and Recovery Strength

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F
Among Subjects				
B (Group)	1	4,015.23	4,015.23	9.08[a]
S (Subjects)	70	30,971.16	442.45	
Within Subjects				
A (Tests)	8	33,391.89	4,173.99	130.76[a]
AB	8	415.38	51.92	1.63
AS	560	17,876.09	31.92	
Total	647	86,669.75		

[a]Significant at $P < .05$

Table 4

Tukey's Test Applied to Initial, Final, and Final Recovery Strength

Tests	Means	Differences Between Means	
		Final Strength	Final Recovery Strength
Initial Strength	49.88	21.97[a]	1.18
Final Strength	27.91	---	20.79[a]
Final Recovery Strength	48.70		---

[a]Significant at $P < .05$

Table 5

Strength Recovery Curve Parameters

Type of Exercise	a_1 (kg.)	k_1 (sec.$^{-1}$)	a_2 (kg.)	k_2 (sec.$^{-1}$)	c (kg.)
Rhythmic	12.01	.05175	17.05	.00244	60.0
Sustained	14.83	.05234	10.05	.00179	50.2

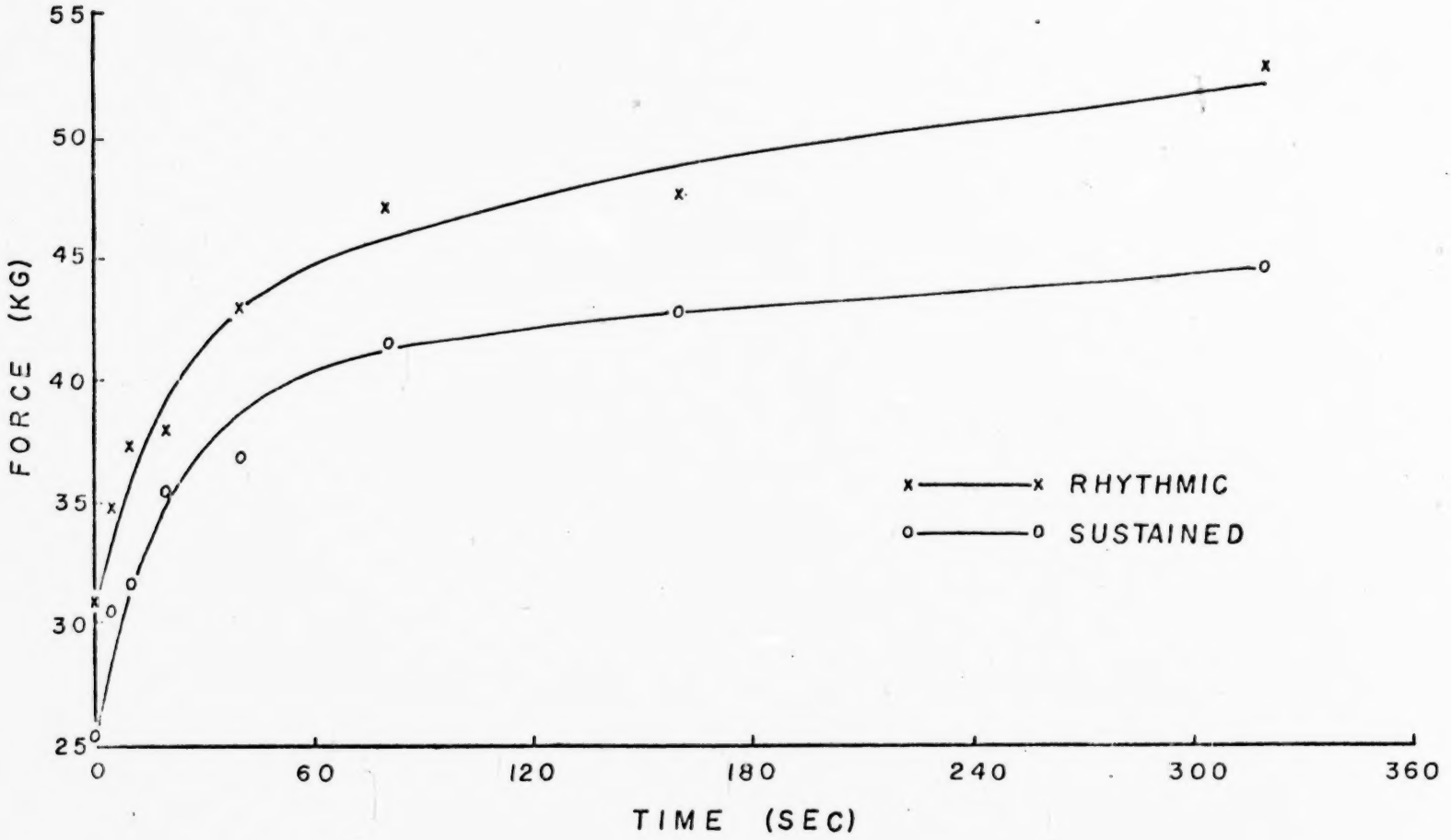

Figure 1

Strength Recovery Curves Following

Rhythmic and Sustained Exercise